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DISINTEGRATION OF THE GRANITIC ROCKS OF THE
DISTRICT OF COLUMBIA.

BY

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INTRODUCTION.

The belt of ancient crystalline rocks bordering along the east side of the Appalachian system south of the glacial limit affords abundant opportunity for the study of rock disintegration and decay as manifested through the somewhat complex processes commonly grouped under the term "weathering." The small area comprised within the northwestern portion of the District of Columbia is particularly favorable to the observation and study of the chemical and physical processes involved. This is due, first, to the fact that in numerous instances one is enabled to study all phases of the transition from sound, fresh rock to arable soil in a single outcrop, where all danger of admixture of foreign material is reduced to a minimum, and, second, to the equally interesting if not important fact that the time-limit of such disintegration can be drawn with a considerable degree of accuracy. The investigations here detailed were undertaken with a view to ascertain, so far as possible, both the



physical and chemical changes which have taken place in this transformation and incidentally to discover the causes thereof.

DESCRIPTION OF LOCALITY.

In the accompanying illustration is shown a very typical exposure as it may be seen today by the roadside on Broad branch, an affluent of Rock creek, nearly a mile north of Pierce's mill. The height of the bluff as here shown is not more than 18 feet. The roots shown in the upper part are from plants and shrubs, as well as from trees—both pines and various forms of hardwood growth, such as cover the hill—and which have here been exposed through the removal of a part of the rock in the work of building the roadway. As is seen in the plate, the rock is divided by three principal sets of joints, one of which, running in a direction nearly north and south and dipping toward the west, gives the flat surfaces facing the observer. A second series cuts across these joints nearly at right angles—that is, east and west—while a third series, running northwest and southeast, cuts both the other series obliquely and dips into the hill at an angle of about 35 degrees from the vertical. Several minor series cut these at various angles, but are not sufficiently evident in the view to need mention.

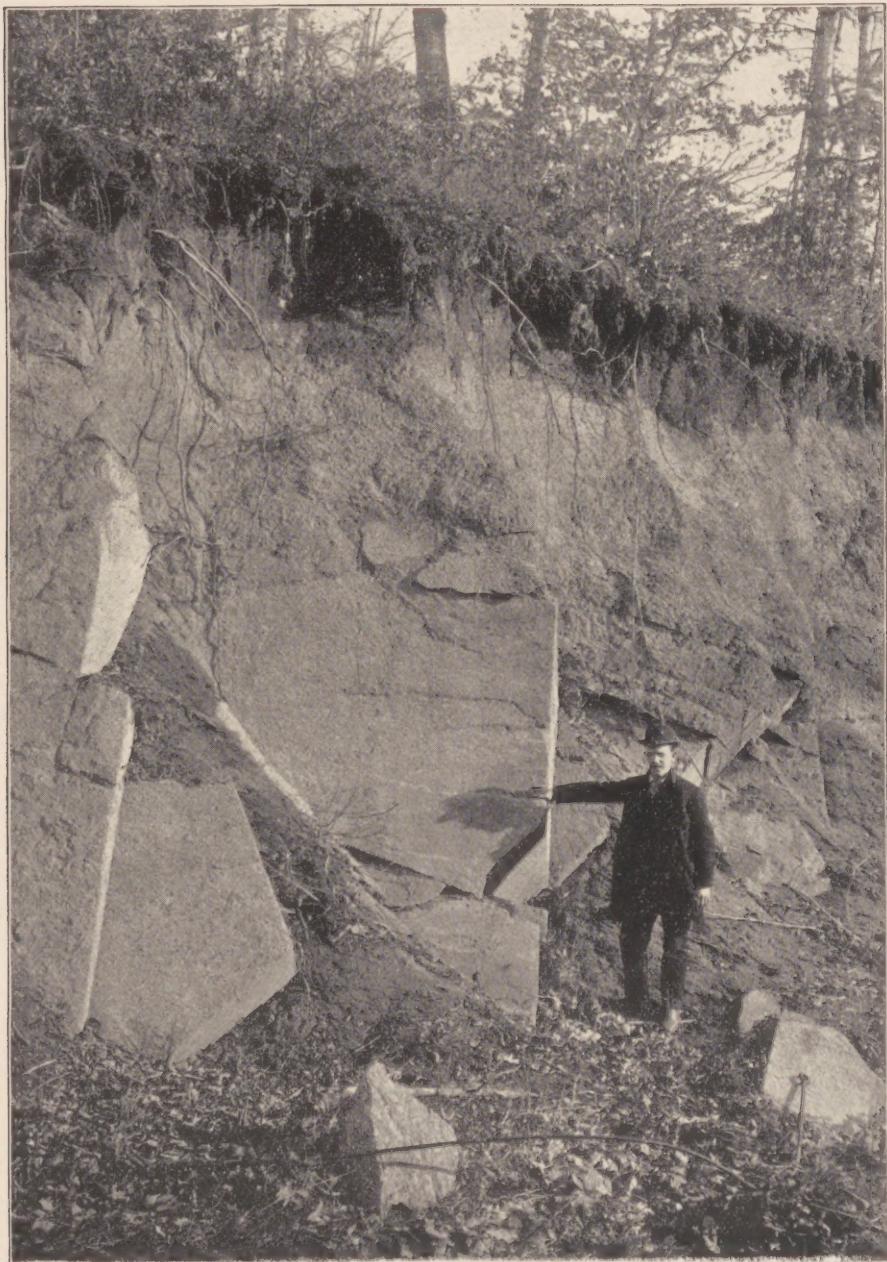
These joints have afforded passageways for the meteoric waters which have been largely instrumental in bringing about the disintegration. The rock in its fresh condition is a strongly foliated micaceous granite,* showing to the unaided eye a finely granular aggregate of quartz and feldspars arranged in imperfect lenticular masses from 2 to 5 millimeters in diameter, about and through which are distributed abundant folia of black mica. In the thin-section the structure is seen to be cataclastic. Quartz and black mica are the most prominent constituents, though there are abundant feldspars of both potash and soda-lime varieties, which, owing to their limpidity, can by the unaided eye scarcely be distinguished from the quartz. The potash-feldspar has in part a microcline structure. Aside from these minerals a primary epidote, in small granules and at times quite perfectly outlined crystals, is a strikingly abundant constituent. Small apatites, a few flakes of a white mica (sericite), and widely scattering black tourmalines and iron ores complete the list of recognizable minerals.

The outcrops from which the samples for the analyses to which I wish to first call attention were selected are shown in the plate. At the very bottom the rock is hard, fresh and compact, without trace of decomposi-

* It is presumably scarcely necessary to state that the writer's views of 13 years ago regarding the possible sedimentary nature of many of the District rocks have undergone a radical change.

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DISINTEGRATING GRANITIC ROCKS IN THE DISTRICT OF COLUMBIA.

tion products other than as indicated by minute infiltrations of calcite from above. Just above the level of the small creek which flows at the foot of the bluff, at the point indicated by the first series of right-and-left joints near the center of the view, the character of the rock changes quite suddenly, becoming brown and friable, though still retaining its form and easily recognizable granitic appearance. A few feet above, a third zone begins, in which the rock is converted into sand and gravel and which becomes more and more soil-like to the top of the bank, where it becomes admixed with organic matter from the growing plants. The amount of organic matter is always quite small, however, and in making the analyses care was taken to remove such as was recognizable in the form of rootlets, leaves and twigs.

ANALYSES AND THEIR DISCUSSION.

BULK ANALYSES.

Bulk analyses of each of the three types—(I) fresh gray rock, (II) decomposed brown, but still moderately firm and intact rock, and (III) soil—yielded Professor R. L. Packard the results given below:

	I.	II.	III.
Ignition	1.22	3.27	4.70
SiO ₂	69.33	66.82	65.69
TiO ₂	not det.	not det.	0.31
Al ₂ O ₃	14.33	15.62	15.23
FeO	3.60	1.69 }	4.39
Fe ₂ O ₃ . . . . .	...	1.88 }	
CaO	3.21	3.13	2.63
MgO	2.44	2.76	2.64
Na ₂ O	2.70	2.58	2.12
K ₂ O	2.67	2.04	2.00
P ₂ O ₅	0.10	not det.	0.055
	99.60	99.79	99.765

It is at once evident from the above that the transition from fresh rock to soil has been brought about with very little change in ultimate chemical composition—an assumption of some 3.5 per cent of water, a change of the ferrous oxide to ferric forms, doubtless more or less hydrated, and a slight decrease in the total amounts of silica, lime, potash and soda being the more conspicuous features. How slight this change has been is best brought out in the accompanying table, in which each analysis is recalculated to a water-free basis. It should be noted, however, that the term water-free, as here used, is not absolutely correct, since the loss on ignition is undoubtedly in part due to carbonic acid from secondary calcite and organic matter.

	I.	II.	III.
SiO ₂	70.47	69.23	69.10
Al ₂ O ₃	14.56	16.18	16.07
TiO ₂.....	....	....	0.31
FeO.....	3.66	1.75}	
Fe ₂ O ₃.....	....	1.95}	4.61
CaO.....	3.27	3.24	2.76
MgO	2.49	2.86	2.77
Na ₂ O.....	2.74	2.68	2.23
K ₂ O.....	2.71	2.11	2.10
P ₂ O ₅	0.10	....	0.06
	100.00	100.00	100.01

An apparent loss of 1.37 per cent of SiO₂; 0.040 per cent of CaO; 0.51 per cent of Na₂O; 0.61 per cent of K₂O, and 0.04 per cent of P₂O₅, or not quite 3 per cent of the total constituents, and a corresponding proportional increase of the less soluble alumina, iron and magnesia, is all the change indicated by a purely chemical, bulk analysis. It is evident that here the chief alteration in the conversion of the barren rock into arable soil is physical, attended probably with a partial change in the mode of combination of the various elements.

ANALYSES OF MATERIAL SEPARATED BY SOLVENTS.

In order to ascertain what this possible change in combination might be, samples of the soil were treated for a period of ten days with (1) cold distilled water; (2) cold distilled water through which carbonic acid gas was kept bubbling; (3) acetic acid, and (4) hydrochloric acid of one-fourth normal strength—that is, one part of acid of the specific gravity of 1.20 to three parts of water. Five hundred grams were used in each of the first three cases and 50 grams in the fourth. The results obtained were as follows:

The pure water extract (1) amounted to but 0.069 grams (0.0138 per cent), which yielded, qualitatively, reactions for potash and soda and a bare trace of lime, but no iron, alumina or silica. The carbonic acid extract (2) yielded 0.0985 grams (0.0197 per cent), which gave reactions for lime, potash, soda, alumina and iron, but no appreciable amount of silica.

The acetic acid extract (3) yielded Professor Packard the quantitative results below:

K ₂ O.....	.024	grams =	.0048	per cent.
Na ₂ O.....	.007	" =	.0014	"
Fe ₂ O ₃.....	.106	" =	.0212	"
Al ₂ O ₃.....	.129	" =	.0258	"
MnO.....	.047	" =	.0094	"
CaO.....	.079	" =	.0158	"
MgO.....	.019	" =	.0038	"
	.411	" =	.0822	"

The hydrochloric acid extract (4) yielded :

SiO_2^*.....	.0545	grams = 0.109 per cent.
Al_2O_3.....	.6620	" = 1.324 "
Fe_2O_3.....	.9061	" = 1.812 "
CaO}.....	.024	" = 0.048 "
K_2O}.....	.0887	" = 0.177 "
Na_2O}.....	.0698	" = 0.139 "
	<hr/>	<hr/>
	1.8051	" = 3.609 "

ANALYSES OF MATERIAL MECHANICALLY SEPARATED.

In order to make more clear the change in physical conditions which the rock had undergone, 400 grams of the pulverulent material, free from roots and other recognizable organic debris, were submitted to mechanical separation by passing through sieves of varying degrees of fineness. The 17 grams tabulated below as "silt" were obtained by washing the 43 grams of material which passed through fine bolting cloth of 120 meshes to the lineal inch, and represents the impalpable mud which remained for some time in suspension, while the 26 grams of "fine sand" sank in the course of a few moments to the bottom of the beaker.

The results of this mechanical separation are as follows :

Silt	17	grams: largest grains 0.1	millimeters in diameter.
Fine sand	26	" " "	0.18 " " "
Sand	45	" " "	0.25 " " "
Sand	15	" " "	0.65 " " "
Sand	44	" " "	1.00 " " "
Sand	94	" " "	1.5 " " "
Coarse sand	118	" " "	2.00 " " "
Gravel	41	" " "	8.00 " " "
Total	400		

The coarser of these particles, like the gravel and the coarse sand, are of a compound nature, being aggregates of quartz and feldspar, with small amounts of mica and other minerals. In the finer material, on the other hand, each particle represents but a single mineral, the process of disaggregation having quite freed it from its associates, excepting, of course, in the case of microscopic inclusions, which could be liberated only by a complete disintegration of the host itself. These particles as seen under the microscope are all sharply angular and in many cases surprisingly fresh and undecomposed. The mica shows the greatest amount of alteration, the change consisting mainly in an oxidation of its ferruginous constituent, whereby the folia become stained and re-

*This silica is that taken up in acid solution only. A much larger amount would have been obtained by treatment of the residue with carbonate of soda solution (see p. 326).

duced to yellowish brown shreds. The feldspars are in some cases opaque through kaolinization, but in others are still fresh and unchanged even in the smallest particles. The finest silt, when treated with a diluted acid to remove the iron stains, shows the remaining granules of quartz, feldspar and epidote beautifully fresh and with sharp, angular borders, the mica being, however, almost completely decolorized and resembling sericite more than biotite. An analysis of this silt yielded the results given further on.*

Column I shows the actual results obtained, and column II the same recalculated to a water-free basis. In columns III and IV are given the attempts to determine the soluble and insoluble portions of the same silt. The soluble portion was that obtained by digestion, without further pulverization, for two hours in hydrochloric acid of one-fourth normal strength, the insoluble residue being treated for a like period with carbonate of soda solution in order to extract the gelatinous silica set free by the acid. This insoluble residue was in the form of a beautiful fine, white sand made up of very sharply angular particles of quartz, fewer feldspars, an occasional epidote and a considerable sprinkling of almost amorphous material, in part kaolin and in part a gum-like substance, evidently representing a transitional stage of the feldspathic alteration into kaolin. The analysis of the soluble portion is unfortunately incomplete, owing to the cracking of a beaker and consequent loss of a portion of the material. The insoluble residue from the two grams treated amounted to 1.206 grams, or 60.3 per cent, and the soluble portion by difference to 0.7949 grams, or 39.7 per cent.

Analysis of Silt.

	I. Actual analysis.	II. Recalcul- ated. Water-free.	III. Soluble portion (39.7 %).	IV. Insoluble portion (60.3 %).
Ignition	8.12	0.00		1.61
SiO ₂	49.39	53.74	{ Extracted in HCl 2.83 Extracted in Na ₂ CO ₃ .. 28.08 }	61.85
Al ₂ O ₃	23.84	25.94	..... 23.21	22.21
Fe ₂ O ₃	3.69	4.01	..... 11.26	1.36
CaO.....	4.41	4.79		4.80
MgO.....	4.60	5.00		traces
Na ₂ O.....	3.36	3.65	{ Undetermined	4.56
K ₂ O.....	2.49	2.71		1.77
	99.90	99.84		98.16

* Unless otherwise stated, all analyses here given were made by the writer of this paper.

From these analyses it would appear that of the 17 grams of silt, representing 4 per cent of the total disintegrated material, only 39.7 per cent is soluble; and, further, that a very considerable proportion of the insoluble residue, as indicated by the high percentages of alkalies and lime, still consists of unaltered soda lime and potash feldspars, the iron and magnesia alone having been largely removed.

CONDITIONS AFFECTING THE RESULTS.

These results are not quite what one would be led to expect from a perusal of the literature bearing upon the subject of rock decomposition. As long since noted by J. G. Forchhammer, G. Bischof, T. Sterry Hunt and others, the ordinary processes of decay in siliceous rocks containing ferruginous protoxides and alkalies consists in the higher oxidation and separation of the protoxides in the form of hydrous sesquioxides and a general hydration of the alkaline silicates, accompanied by the formation of alkaline carbonates, which being readily soluble are taken away nearly as fast as formed. More or less silica is also removed, according to the amount of carbonic acid present—a portion of the alkalies forming soluble alkaline silicates when the supply of the acid is insufficient to take them all up in the form of carbonates. The apparent anomaly here shown is partially explained by examination of the various separations with the microscope. Thus the low percentage of silica is found to be in large part due to the fact that the residual quartz granules are in many cases too large to pass the 120-mesh sieve, or, if passing, have been largely separated in the process of washing. Further, it is found that the sifting has served to concentrate the small epidotes in the fine sand, and a portion of them have even come over with the silt. The presence of this epidote also explains in part the high percentage of lime shown, since the mineral itself carries some 20 to 24 per cent. of this material. The large percentages of magnesia, soda and potash cannot, however, be thus accounted for, and we are led to infer that either these elements are there combined in minute amorphous zeolitic compounds, unrecognizable as such under the microscope, or, as seems to me more probable, the feldspathic constituents to which the alkalies are to be originally referred have undergone a mechanical splitting up rather than a chemical decomposition. This view is to a certain extent borne out by microscopic studies, but it is difficult to measure by the eye the relative abundance of these constituents with sufficient accuracy to enable one to form any satisfactory conclusion. The magnesia must come from the shreds of mica, many of which, from their small size and almost flocculent nature when decomposed, would naturally be found in the silt obtained as stated.

It is to be noted that the magnesia, together with the iron, exists almost wholly in a soluble form.

ANALYSES OF MATERIAL FROM OTHER LOCALITIES.

Not wishing to attach too much importance to analyses of samples from a single locality, others were obtained from along the same belt. In I of the columns below, is shown the composition of a soil from the road-cut west of Pierce's mill, and in II and III material from the deeper cut where this road crosses Connecticut avenue extended, number II being from some 3 feet beneath the surface where it was overlaid by a thin layer of the Potomac gravel, and III from the bottom of the cut some 20 feet below the present surface. The last sample, though sufficiently soft to be readily removed with the fingers, showed scarcely any of the oxidation which discolors the superficial portions, thus indicating that oxidation itself is not an essential part of the disintegrating process, but merely incidental to it. In column IV is given an average of the three analyses, and in V the same calculated on a water-free basis. For purposes of comparison the results given in column III, page 323, are here repeated in column VI.

	I.	II.	III.	IV.	V.	VI.
Ignition	5.51	3.87	3.97	4.45	.....	.....
SiO ₂	64.25	64.87	63.42	64.15	67.13	69.10
Al ₂ O ₃)	19.97	21.32	23.08	21.26	23.29	20.99
Fe ₂ O ₃)	3.12	3.01	2.69	2.94	2.07	2.77
MgO	3.18	2.90	3.01	3.03	3.17	2.76
CaO.....	2.17	2.39	2.15	2.24	2.34	2.10
K ₂ O.....	1.55	1.86	1.77	1.72	1.80	2.23
Na ₂ O	99.75	100.22	100.09	99.79	99.80	99.95

It should be stated that in all these cases special care was exercised in securing samples from areas which had never been under cultivation in order that there might be no possible contamination or acceleration of decay through the action of fertilizers or of plowing. Equal care was taken to obtain material in place and where it had undergone only the leaching of surface waters percolating downward from above. The results, though showing a somewhat more advanced condition of decay, agree even more closely than could be expected from samples collected from widely separated localities.

TIME-LIMIT OF DISINTEGRATION.

A possible time-limit to the beginning of this disintegration is furnished by the Potomac (Cretaceous) and more recent deposits of the region.

While in the first case described the disintegrated granitic material forms the present surface soil, there are abundant street and road cuttings in the northwestern part of the District where the unconsolidated sands and gravels of the Potomac and Lafayette formations as described by Messrs McGee* and Darton are to be found overlying it at this same or greater altitudes and in beds of no inconsiderable thickness. In all such cases the line of demarkation between the two is well defined and there is no apparent admixture of materials.

Although both the Potomac and Lafayette gravels contain materials undoubtedly derived from these older crystalline rocks, yet we do not find along the line of contact anything to indicate that they were laid down on surfaces such as now exist or were other than fresh and hard. There are included in the lower part of the gravel none of the large angular masses of quartz from the veins, such as now so commonly dot the surface, nor natural joint-blocks of the granite. On the supposition that the beginning of the present decomposition antedates the laying down of these gravels, we must assume a submergence and deposition in waters so quiet as not to disturb the rotted materials. That such a condition is impossible becomes apparent when we consider the character of the deposits themselves. As described, they consist of quartzite pebbles derived evidently from the axial quartzites of the Blue ridge, quartz pebbles identical with the vein-quartz of the region and from which they were evidently derived, and a loosely consolidated arkose made up of angular grains of quartz and of feldspar or flakes of kaolin, scales of mica, etcetera. To this list I would add for the region about Washington an abundant sprinkling of well rounded pebbles of a felsitic quartz-porphry, which, like the quartzite, was evidently derived from the Blue ridge. The character of the accumulations, as Mr McGee states,† are—

“Just such as would be formed by the assortment and deposition of the different materials by ‘*powerful currents*’ (author’s italics), but the quantity of coarse material is greater than would result from simple admixture of the disintegrated gneiss of the Piedmont zone and such proportion of the Blue Ridge quartzite, vein-quartz, etcetera, as appear to be mingled with it, suggesting that the portions of the formation now exposed were littoral, and that the finer materials were swept into deeper, offshore waters.”

The pebbles of this formation, it should be stated, are almost invariably well rounded by water-action and occur of all weights up to 200 and more pounds. It seems safe to assume that these somewhat sporadic, larger forms are due to drifting ice and for our present purposes may be left out of consideration.

* Am. Jour. Sci., February, March, April and May, 1888.

† Op. cit., February, 1888, p. 139.

Aside from these, an abundant sprinkling of well rounded pebbles of from one to 5 or 6 pounds weight each form one of the most characteristic features of the gravels. It seems impossible that such material could have been brought to its present position except by the aid of currents or wave-action so energetic as to erode the then existing decomposed granitic material which the lithologic character of the Potomac formation, as above given, tends to prove existed.

The point which I now wish to make is, however, that all such material was removed from its position *in situ* prior to the deposition of these gravels. The fact that everywhere along the lower part of the deposits there is a notable lack of the angular quartz fragments and jointed blocks of granite such as now form so conspicuous a feature leads, as it seems to me, irresistibly to the conclusion that prior to their deposition all loose and partially decomposed matter was eroded away and the later deposition made upon hard and comparatively fresh surfaces. Hence the disintegration as we now find it, extending in some cases to a depth of 50 or more feet, is almost wholly post-Cretaceous.

That this apparently rapid rate of decomposition is not anomalous is well illustrated in a large dike of diabase at Medford, Massachusetts, the petrographic nature of which has been made known by Dr Hobbs.* Portions of this dike are in an advanced stage of disintegration, which is undoubtedly postglacial. The writer hopes to describe the changes which have here taken place in another paper.

As a matter of passing interest and as bearing upon the same general subject, I may mention the fact that the pebbles of felsitic rock noted as occurring in the Potomac gravels are, as a rule, in a condition of such complete decomposition (kaolinization) as to fall to pieces except when handled with the greatest care. Indeed, wherever exposed through the cutting of streets, they fall away quickly to loose sand. Nevertheless, the outlines of these pebbles are sharply oval and the surfaces smooth and almost polished. They are beyond question water-worn pebbles, and as such could only have assumed their rounded form when their materials were in an entirely fresh and undecomposed condition—that is to say, their decomposition was posterior to their deposition, or at least to the time of their becoming water-worn.

This particular occurrence I regard of interest as showing, first, the great depth to which disintegration can be carried without excessive decomposition, and, secondly, the relative rapidity of the process. I should add that in areas examined farther to the west and south, beyond the limit of the Cretaceous submergence, I find similar rocks in a state

* Bull. Museum of Comparative Zoölogy, vol. xvi, no. 1, 1888.

of much more advanced decomposition, being in most cases at the immediate surface reduced to the condition of residual clays.

CAUSES OF DISINTEGRATION.

It is evident from what has gone before that the changes which have taken place in the mass of rock are as much in the nature of disintegration as decomposition. The question, then, very promptly arises, what are the agencies which have been instrumental in bringing about a disintegration which in extreme cases extends to a depth of 50 feet and upward.

It is customary to divide the forces commonly active in promoting rock-weathering into two groups—physical and chemical. Of the physical agencies, temperature changes alone need be considered in this connection;* of the chemical agencies, oxidation, hydration and solution.

It has been abundantly demonstrated in the work of the various experiment stations that at a depth of a few inches beneath the surface the daily variation in temperature is very slight, and we may safely assume that at depths of a few feet both the annual and daily variations are also so small as to be practically inoperative. The purely physical agencies may be therefore omitted from further consideration.

Of the chemical agencies, it is evident that the process of solution has not been sufficiently active to carry away more than an extremely small proportion of the material, but has contented itself with bringing a fractional part of the elements into a new state of combination. These facts, would seem to render it very doubtful if bacterial agencies, as suggested by A. Müntz and others,† have operated to any appreciable extent.

Oxidation has manifested itself in the superficial portions in the partial destruction of the protoxide silicates, but even this action to a large extent ceases at a depth of 20 feet below the surface.

Of all the agencies enumerated, hydration seems most pronounced and most nearly universal. Now, hydration in a rock-mass, without loss of any constituent, necessitates expansion, and as the various minerals undergoing this process will expand unequally, a tendency toward disintegration is manifested, even when the process has stopped short of the complete kaolinization of the feldspars. This fact was impressed upon me in a very striking manner some years ago, and inasmuch as I do not

* In the discussion which followed the reading of this paper before the Geological Society of Washington in January, 1895, the question was raised as to the possible efficacy of capillarity in promoting disintegration. The writer can only say that he is unable to conceive of the direct physical action of capillarity as being other than neutral. As a secondary factor in promoting hydration, it is undoubtedly of importance.

† *Comptes Rendus de l'Academie des Sciences*, vol. cx, 1890, p. 1370.

find reference to like phenomena in existing literature I may be excused for describing it somewhat in detail.

While excavating in the tunnel for the water-works extension in Washington, sharply angular natural joint-blocks of granitic and dioritic rocks with smooth, even faces, were brought to the surface from varying depths up to a hundred and some odd feet. Much of the material was perfectly fresh and sound, and has been utilized for road-making and building purposes. Much, on the other hand, while apparently fresh and showing on casual inspection no signs of decomposition, gave forth only a dull sound when struck with a hammer and showed a lusterless fracture. Blocks of this last type nearly always rapidly disintegrated into coarse sand after short exposure, though manifesting no other sign of mineral-ogic change than a whitening of the feldspars. So marked was this feature that even the workmen noticed it, and on more than one occasion samples of this or the sound rock were brought me by builders who questioned its durability, inasmuch as some of the material "slacked like lime," as they expressed it, on exposure.

My explanation has always been that the various minerals composing the rock (with the exception of the quartz) underwent a partial hydration from percolating waters, but, held in the vise-like grip of the surrounding rocks, were unable to expand to the extent of loss of cohesion and consequent disintegration. As soon as freed from compression expansion and presumably further hydration took place, the mass became spongy, and, freely absorbing water, fell into sand and gravel.

This idea led me to make a few experiments toward ascertaining the actual amount of expansion the rock undergoes during this transformation. Barring the error due to loss of material by solution, it is evident that a fair approximation may be gained by a comparison of the weight, bulk for bulk, of the fresh and decomposed material. It being obvious that in order to fulfill existing conditions no great refinement of methods was essential, I contented myself with taking a quantity of the air-dried material and measuring it in straight, cylindrical glass vessels, bringing it to the approximate condition of the soil by tamping with water, and afterward drying and weighing. By comparing the weights per cubic centimeter thus obtained with the weight of a cubic centimeter of the fresh rock, as shown by its specific gravity, I was able from an average of several determinations to obtain an approximation of 1.88, which represents with a fair degree of accuracy the average amount of expansion which the rock has here undergone in passing from its fresh condition into that of undisturbed soil a foot beneath the surface.

